Bio-Medical Materials and Engineering 24 (2014) 1951–1958
DOI 10.3233/BME-141004
IOS Press

Fabrication of multilayer-PDMS based microfluidic device for bio-particles concentration detection

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Abstract. This paper discusses the process technology to fabricate multilayer-Polydimethylsiloxane (PDMS) based microfluidic device for bio-particles concentration detection in Lab-on-chip system. The micro chamber and the fluidic channel were fabricated using standard photolithography and soft lithography process. Conventional method by pouring PDMS on a silicon wafer and peeling after curing in soft lithography produces unspecific layer thickness. In this work, a multilayer-PDMS method is proposed to produce a layer with specific and fixed thickness micron size after bonding that act as an optimum light path length for optimum light detection. This multilayer with precise thickness is required since the microfluidic is integrated with optical transducer. Another significant advantage of this method is to provide excellent bonding between multilayer-PDMS layer and biocompatible microfluidic channel. The detail fabrication process were illustrated through scanning electron microscopy (SEM) and discussed in this work. The optical signal responses obtained from the multilayer-PDMS microfluidic channel with integrated optical transducer were compared with those obtained with the microfluidic channel from a conventional method. As a result, both optical signal responses did not show significant differences in terms of dispersion of light propagation for both media.

Keywords: SU-8 mold, multi-layer polydimethylsiloxane, microfluidic, bio-particles

1. Introduction

In recent years, a microfluidic device is applied as a method for biological and chemical samples due to its benefits such as miniaturisation, smooth integration with detection components and therefore, able to perform fast detection since it can provide on-site laboratory solution [1,2]. Bio-particles can be classified as deoxyribonucleic acid (DNA), protein molecules, bacteria, viruses, spores, pollen and biological toxin in a fluid. They have specific optical characteristics depending on their physical structures and material properties [3,4]. These optical properties can be used to detect the present of the particles inside the human blood by integrating an optical transducer with the microfluidic channel.

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Polydimethylsiloxane (PDMS) is the most widely used as the material in the microfluidic fabrication since it is biocompatible with these samples, low cost and optically transparent in frequencies range from 240 nm to 1100 nm.

Previous works on direct measurement of UV absorbance using optical transducer method were reported [5,6] in which the microsystem consists of a UV LED as the light source able to transmit light at precise wavelength through a quartz container of Deoxyribonucleic acid (DNA). Due to the demand of portable and small micro size of detection device, the integration of an optical transducer into a microfluidic system has been realized in the other previous works. A light path length is one of the design requirements that need to be considered as it can increase detection sensitivity in the integration of microfluidic with optical transducer. However, most of the previous work required waveguide in order to guide the light into detection device [7–9]. The thickness of the chamber layer was used as the light path and can be also improved without using the waveguide as reported in these works [10,11].

In this work, a microfluidic employed PDMS multilayer as the microfluidic channel and chamber is formed for direct measurement of bio-particles concentration in an ultraviolet range. The thickness of the PDMS layer determines the optimum light detection in the chamber. For the light to optimally pass through the PDMS microfluidic chamber, a multilayer PDMS with precise thickness is required in this application in order to achieve light detection and optimal absorption sensitivity. The desired total thickness of the PDMS layer after bonding is unable to achieve without spin coat process since it will produce imprecise thickness layer. By spin coating, layer thickness of around 220 μm can be produced [12]. Therefore, a multilayer-PDMS based microfluidic system is implemented in order to achieve precise layer thickness which also acts as a light path length. The fabrication results are illustrated through scanning electron microscopic and also microfluidic testing with optical transducer are presented and discussed.

2. Methodology

2.1. Fabrication of SU-8 as a master mold

The SU-8 master mold was first fabricated using standard photolithography method as depicted in Figure 1(a). An inch of a silicon wafer was used as a substrate and treated using conventional silicon cleaning. SU-8 2075 from 2000 series of Micro-Chem was used in order to achieve 80 μm microchannel mold thickness. The SU-8 was deposited on a Si substrate then it was pre-spun at 500 rpm for ten seconds and ramped at 2500 rpm for 20 seconds for the desired thickness. The mold was soft baked at 65°C for 5 minutes and continued bake at 95°C for another 10 minutes before exposing to UV light at 365 nm with 2.6 mW/cm2 light intensity (Karl Suss MJB 3) through a transparency mask for 60 seconds. After exposure, it was baked again (65°C for 2 minutes, 95°C for 8 minutes) followed by developed in SU-8 developer for 8 minutes. After the pattern had appeared, the mold was rinsed using isopropyl alcohol (IPA) and blow dried using nitrogen. As a final process, the mold was hard baked for 30 minutes at 150°C.

2.2. Conventional fabrication process of double layer PDMS

The conventional method for fabricating PDMS using standard soft lithography was initiated by mixing the PDMS elastomer base (Sylgard® 184 from Dow Corning) with curing agent, ratio of 10:1. The mixture was de-gassed in a vacuum chamber until air bubble was completely removed. In order to

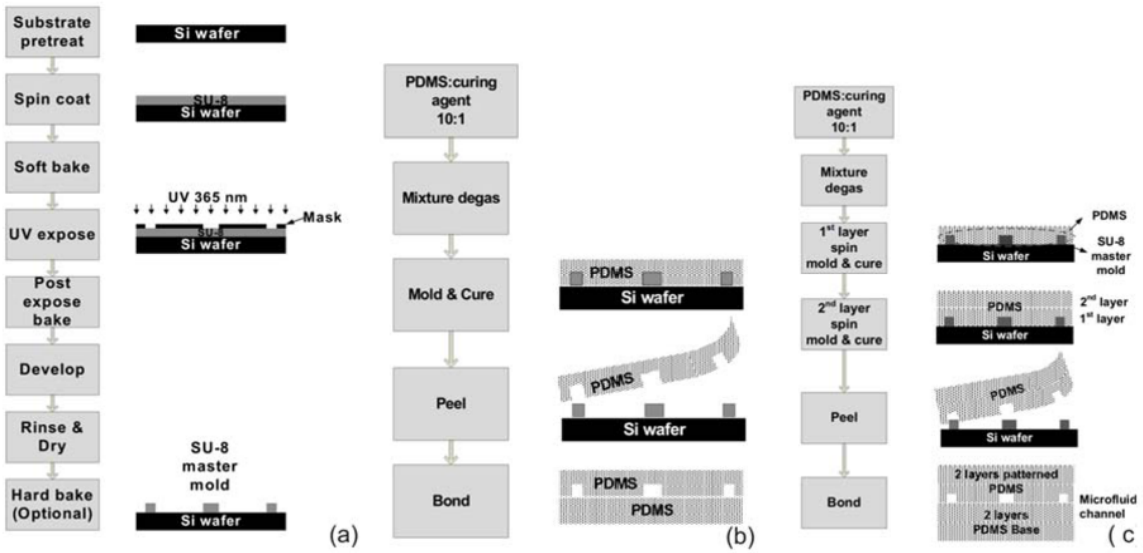

Fig. 1. Fabrication process: (a) process flow and schematic for 80μm film thickness SU-8 master mold, (b) process flow and schematic for poured 80 μm depth double layer PDMS microfluidic channel and (c) process flow and schematic for spin coated multilayer-PDMS microfluidic channel.

obtain the PDMS pattern layer, the mixture was poured on the SU-8 master mold and cured in an oven for one hour at 60°C. After peeling process, the microfluidic channel can be produced by sealing the pattern layer with a flat surface of PDMS produced by a similar process. All process is illustrated in Figure 1(b).

2.3. Fabrication process of multilayer-PDMS

The fabrication process for achieving a desired multilayer PDMS of micron size is shown in Figure 1(c). The mixture was de-gassed in desiccator until no longer air bubbles visible. It was then poured on top of SU-8 master mold. Initially, the mixture was pre spun at 500 rpm for 10 s in order to spread over uniformly on the entire mold. The layer was then spun at lower speed at another 500 rpm for 10 s. Next, it was put in the oven for curing process at 60°C for 1 hour. This procedure was repeated for another layer in order to achieve the desired thickness at approximately 500 m. The patterned layer was then peeled after cured in an oven at 60°C for 1 hour. Finally, the enclosed multilayer-PDMS microfluidic channel can be obtained by sealing the patterned layer with PDMS flat surface as a base obtained from a similar method.

3. Results and discussion

The SU-8 master mold with 3 mm diameter of the detection chamber, 80 μm fluidic channel depth and 2 mm inlet/outlet diameter was successfully fabricated using standard photolithography method. The associated PDMS microfluidic channels were also successfully fabricated using conventional and multilayer PDMS fabrication process. Figure 2 shows the cross-sectional images for both SU-8 mold

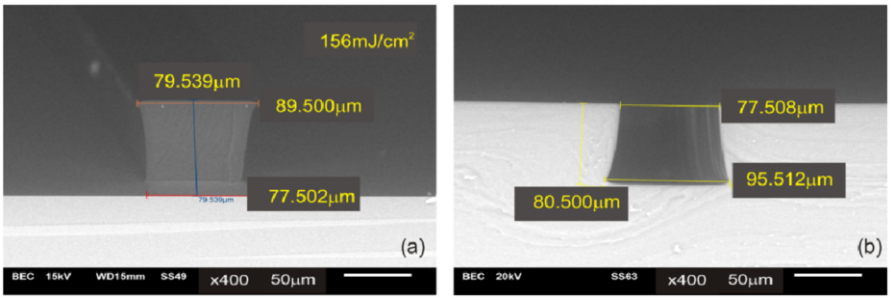

Fig. 2. Cross-sectional images for dimension: (a) SU-8 master mold thickness and (b) PDMS microfluidic channel depth.

and PDMS microchannel. The cross section is important to ensure the quality of the mold master structure and for further observation of the thickness of the molded structure under scanning electron microscopy. It was shown that SU-8 structure with high-aspect ratio more than one was produced using UV exposure at 156 mJ/cm^2. A straight vertical wall with over developed as high as 5% is seen which is possibly due low penetration of UV light from the UV source causing the SU-8 sidewall slightly shrunken at the lower part as shown in Figure 2(a). While in Figure 2(b) shows a cross section image of the PDMS microfluidic channel after unmolding with depth of 80.5 µm, replica top width at 95.512 µm and replica bottom width at 77.508 µm, respectively.

As the PDMS thickness acts as the necessary light path to guide the light into the chamber, the desired total thickness of the PDMS layer after bonding should be precise and reproducible layer structure with fix thickness that was able to achieve through spin coating process. PDMS samples were peeled from three different mold structures that made from conventional lithography process and produced imprecise total thickness. This problem is due to the typical procedure in molding process was only poured the PDMS mixture on the mold and leave to cure. Through spin coat process of PDMS mixture on SU-8 mold, the mixture was deposited evenly on the entire mold and desired layer with specific thickness of PDMS was able to achieve. One layer of spin-coated PDMS at 500 rpm for 10 seconds, resulted to a thickness of approximately to 250 µm single-layer coating. This parameter is considered as too thin, yield uneven PDMS surface and structure as shown in the SEM cross-sectional image (Figure 3(a)). Moreover, is difficult to peel after curing and may tend to stick to the mold.

Therefore, two layers of PDMS coating are required since one layer has not fulfilled the microfluidic requirement as discussed before. Two invisible layer PDMS with the thickness at 445.751 µm as depicted in Figure 3(b) was constructed by adding another layer after the first spin coat and cure. The overall multilayer PDMS microfluidic created through fabrication process contains four layers. The first layer for each design and base is used as a surface bonding. As to increase the thickness and also the adhesiveness strength, another layer was deposited to both design and base since one layer is too thin and difficult to peel and produce an uneven surface. This second layer also serves as a protective layer for the enclosed microfluidic channel. Based on Figure 4, shows a cross-sectional closed-up for the bonding interface comparison between PDMS-PDMS layer (double layer) produced from conventional fabrication process and multilayer-PDMS from suggested method. The bonding line interface which is marked by the dashed line is noticeable in Figure 4(a). Multilayer-PDMS produced in strong bonding since the interface line is invisible (Figure 4(b)). The layer interface between layer 1 and 2 and layer 3 and 4 are also invisible since it was purely cured. A common problem may arise while bonding process that is the air trapping between the PDMS interface layer. This problem can be removed by simply pressing the sheet with finger pressure.

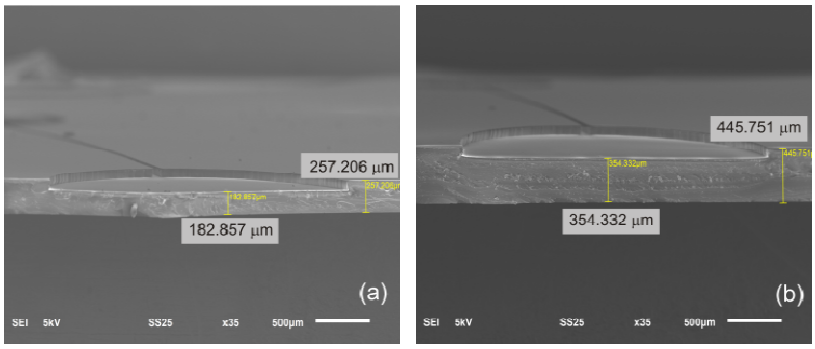

Fig. 3. SEM images PDMS through spin coat process (a) single layer (b) double layer.

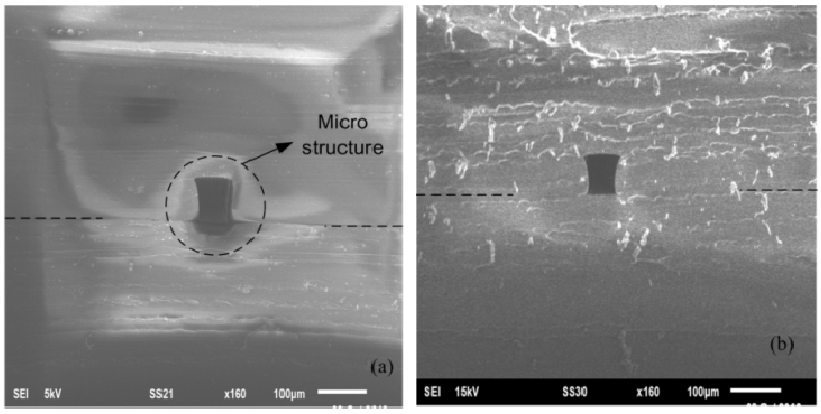

Fig. 4. Cross-sectional of the bonding interface: (a) PDMS-PDMS layer (double layer) and (b) PDMS-multilayer.

Figure 5 show a schematic configuration of particle detection using optical transducer and also the microfluidic and optical transducer setup testing. As depicted in Figure 5(b) the optical transducer consists of a deep UV-LED-AlGaN collimated light source with 260 nm peak wavelength and photodetector. The light signal emitted from the LED with a modulation frequency of 1 kHz is travelled along in a chamber of PDMS microfluidic in which the UV light interacts with bio-particles by absorbing the light. The transmitted light is then detected by a vertical photodetector 1 cm from the light source with reduced intensity which can give the information about the bio-particles concentration. The photodetector is a low dark current, high speed and low noise Silicon Carbide (SiC) UV photodiode which is capable of converting the light into a photocurrent. As the photocurrent detected by the photodiode is very low, the signal is amplified, conditioned and converted to a proportional voltage by the signal conditioner and amplification.

The microfluidic channel was tested with colored dye injected through the fluid interconnectivity directly to the inlet as the set up testing is shown in Figure 5(b). In order to observe bubble trap inside the microchannel, de-ionized water was first injected using a syringe. Then the colored dye was injected using auto syringe pump (TS-2A/L0107-2A, Longerpump). All the samples were observed through GE-5 Digital Microscope. Throughout the microfluidic testing, it shows that the fluid can flow without any leakage and blockage especially at the fluid interconnection and the micro channel part. The microfluidic channel was then tested using the optical transducer.

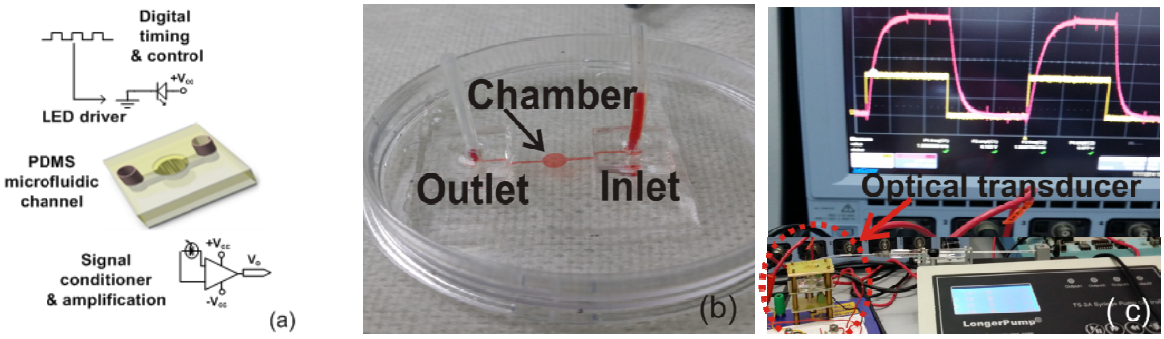

Fig. 5. (a) Schematic configuration of the optical transducer and (b) microfluidic testing with colored dye (c) setup testing of microfluidic channel with optical transducer.

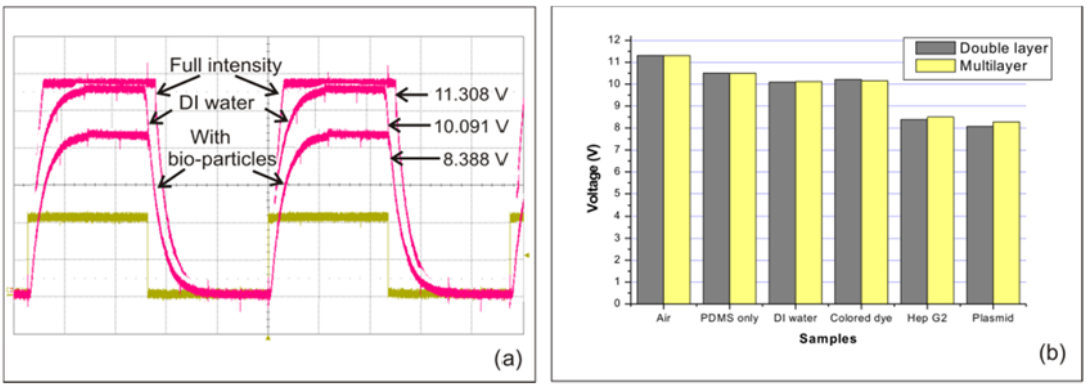

Fig. 6. (a) Optical signal response to samples (b) voltage responses to samples.

Figure 6 shows results of a PDMS microfluidic testing by varying analytical samples. The samples that were analyzed consist of air, PDMS with de-ionized water and colored dye, PDMS with bio-particles that were extracted from HEP G2 and plasmid. The light intensity received by photodiode is directly proportional to the voltage. Therefore in this case, the output signal is displayed in voltage. In Figure 6(a), the optical signal represents light intensity in air media without PDMS and fluidic medium is 11.308 V, which is considered as full light intensity received by photodiode. It is also shown that, there were responses of photodiode when the light struck through PDMS chamber filled with analytical samples. From the observation, the voltage was slightly decreased when ultraviolet light was transmitted through the chamber with de-ionized water and significantly decreased due to light absorption by bio-particles. Finally, the performance of the microfluidic and optical transducer were further investigated by injecting four samples into the chamber of the microfluidic made from the double layer and multilayer PDMS. The voltage reading that associated with the light absorption are shown through analytical curves in Figure 6(b). When PDMS microfluidic channel was placed in between the LED and photodiode, the voltages were slightly reduced approximately down to 0.8 V for both double layer and multilayer PDMS microfluidic. This voltage drop is due to dispersion of light propagation from the LED through the PDMS layer. While both PDMS chambers filled with de-ionized water and colored dye, the voltage reading was slightly reduced. Obviously, the voltage reduced drastically due to light absorption when both chambers were filled with bio-particles from HEP G2 and plasmid. Fur-

thermore, the results show that multilayer-PDMS based microfluidic channel did not show significant differences in terms of dispersion of light propagation as compare to double layer PDMS.

4. Conclusion

A multilayer-PDMS based microfluidic for optical detection of bio-particles concentration has been fabricated and analyzed. The fabrication of multilayer PDMS for the microfluidic part of the system with a deep channel and chamber was investigated. From this approach, very strong bond between two PDMS layers was achieved. With the multilayer concept, the material structure has been improved, and it is expected to increase the quality of the chamber structure and light detection. Another advantage, better chamber structure and the specific light path length of approximately to 1000 μm were resulted. Only slightly light dispersion occurred when the multilayer PDMS was tested using optical transducer. The multilayer PDMS microfluidic channel also has been tested by injecting bio-particles. It showed that the light intensity was reduced as the voltage dropped significantly approximately to 2 V which confirmed the light absorption of the bio-particles inside the chamber.

Acknowledgement

This work is supported by MOSTI Research Grant: Nanofund/NND/(1)/TD11-002 (Development of lab-on chip for peripheral blood stem cell isolation and rapid detection of tropical diseases from blood).

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